INTERNATIONAL JOURNAL OF RESEARCH AND SCIENTIFIC INNOVATION (IJRSI)
ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue I January 2026

Integrated Geophysical and Hydrochemical Assessment of Groundwater in Alor and Its Environs, Southeastern Nigeria

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DOI: https://doi.org/10.51244/IJRSI.2026.13010035

Received: 02 January 2026; Accepted: 07 January 2026; Published: 24 January 2026

ABSTRACT

This study presents an integrated geophysical, and hydrochemical assessment of groundwater in Alor and its environs in Idemili South Local Government Area of Anambra State, Nigeria. The research utilized geological mapping, vertical electrical sounding (VES), and hydrochemical analyses to characterize the subsurface lithologies, aquifer systems, and groundwater quality. Geological mapping revealed that the area is predominantly underlain by the Nanka Formation, consisting mainly of poorly consolidated sands, claystone, siltstone, and ironstone beds. Geophysical investigations delineated five to six geo-electric layers, with aquiferous zones identified at depths of 117-155 m and resistivity values ranging from 1,213 to 5,442 Ωm. Hydrochemical results indicate that surface waters are slightly acidic, elevated biochemical oxygen demand (BOD), Heavy metal (Hg, Cd, Ar, and Pb) concentrations are high, and *E. Coli* are found in all the samples, rendering them unsuitable for drinking without treatment. The findings collectively reveal the presence of unconfined aquifers with favourable hydrogeological conditions yet poor water quality, highlighting the need for proper treatment before domestic use. This integrated assessment contributes to improved groundwater development, sustainable water resource management, and enhanced community wellbeing.

Keywords: Groundwater, Geophysical Survey, Hydrochemical analysis, Vertical Electrical Sounding, Nanka Formation, Water Quality.

INTRODUCTION

Groundwater plays a crucial role in meeting domestic and agricultural water needs in Nigeria, particularly in areas where surface water is unreliable or contaminated (Offodile, 2002). In southeastern Nigeria, growing population pressures and expanded land use have increased dependence on groundwater resources, making scientific assessment of aquifer systems essential for sustainable water supply (Ehirim & Ebeniro, 2010). Effective groundwater development requires a clear understanding of subsurface geological conditions and aquifer characteristics, which strongly influence groundwater occurrence and productivity (Fetter, 2014).

Alor and its surrounding communities lie within the northern transitional zone of the Niger Delta Basin, one of Africa's most extensive sedimentary basins, composed of the Akata, Agbada, and Benin Formations (Doust & Omatsola, 1989; Reyment, 1965). In this region, the dominant geologic unit is the Nanka Formation of the Ameki Group, characterized by porous and permeable sands interbedded with clay and silt layers. These features make it an important aquifer system capable of storing and transmitting significant quantities of groundwater (Nwajide, 2013; Nwajide & Hoque, 1979).

Integrated approaches have proven effective in delineating aquifer boundaries, determining groundwater depth, and evaluating water quality (Todd & Mays, 2005). Among these methods, Vertical Electrical Sounding (VES) is widely applied across Nigeria for identifying aquifer zones and determining subsurface layering in sedimentary terrains (Ako & Olorunfemi, 1989; Oseji *et al.,* 2005). Additionally, water quality assessments are essential, as many communities in southeastern Nigeria report contamination from heavy metals, wastewater infiltration, and microbial pollution (Ezeh & Ugwu, 2010; Okpoko, 2017).

This study applies an integrated geophysical, and hydrochemical approach to assess groundwater potential in Alor and environs. The findings aim to enhance borehole success rates, improve groundwater management, and support sustainable water development for the area.

Location and accessibility of the study area

Alor and its environs are located in Idemili South Local Government Area of Anambra State, southeastern Nigeria. Geographically, the town lies between latitudes 6°04′0″N and 6°06′8″N and longitudes 6°56′11″E and 6°58′23″E. The area is characterized by undulating terrain, with several small valleys that influence surface drainage patterns. Accessibility to the study area is relatively easy due to its connection to several major transportation routes. The town is linked to the broader Anambra Road network through the Nnobi-Nnewi Road and the Awka–Onitsha Express corridor, which serve as major regional access routes. Within Alor itself, the Oraukwu-Alor Road**,** Nnobi-Alor Road, and Ozubulu-Alor Road provide dependable connectivity to neighbouring towns such as Nnobi, Ideani, Oraukwu, and Nkpor. These major roads are complemented by several minor roads and footpaths, including the Eti-Ili Road**,** Ụmụokwu–Ụmuedim Road**,** Ụlọr Road, and the Ụmụoji Link Road, which enhance intra-community mobility and accessibility to residential areas, farmlands, and water points.

The presence of nearby economic hubs also contributes to the area's accessibility and population flow. Prominent markets such as Nnobi Market, Oye Market, Nkpor Main Market, and Afor Nnokwa Market are located within short driving distance from Alor, supporting trade activities and daily commuting. Within the town, smaller local markets, including community stalls and periodic village markets, facilitate the exchange of agricultural produce and household goods.

Fig. 1: Location map of the study area

Geology of the study area

The study area lies within the Niger Delta Basin, one of Africa's largest and most economically significant sedimentary basins. The Niger Delta Basin is composed of three major lithostratigraphic units, the Akata, Agbada, and Benin Formations, representing marine, paralic, and continental depositional environments, respectively (Doust & Omatsola, 1989; Reyment, 1965). Toward the basin's northeastern margin, where Alor is situated, these formations interfinger with the Imo Formation, Ameki Group, and Ogwashi-Asaba Formation**.** (Nwajide, 2013; Obaje, 2009).

The dominant geologic unit in Alor and its environs is the Nanka Formation, a member of the Ameki Group of Eocene age. The Nanka Formation consists primarily of poorly consolidated, medium-to-coarse-grained, cross-bedded sand**s** that are friable and highly porous. These sands are interlayered with thin beds of claystone, siltstone, and shale, reflecting alternating periods of higher and lower energy depositional environments (Nwajide & Hoque, 1979). Ironstone lenses and ferruginized horizons also occur locally within the sequence, often resulting from post-depositional cementation and oxidation.

The sands of the Nanka Formation are particularly noteworthy for their excellent porosity and permeability, which make them one of the most productive aquifer systems in southeastern Nigeria. Their high hydraulic

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue I January 2026

conductivity allows for significant groundwater storage and movement, contributing to the formation of confined and semi-confined aquifers at depth. These characteristics explain the widespread reliance on boreholes and groundwater extraction within the region.

Stratigraphically, the Nanka sands overlie the Imo Formation, a predominantly shale-rich unit, and are in turn overlain in some parts of southeastern Nigeria by the Ogwashi-Asaba Formation, composed of lignite, clay, and interbedded sands. Although the Ogwashi-Asaba Formation does not appear prominently within the mapped area at Alor, its regional presence is well documented (Obaje, 2009; Nwajide, 2013). The sedimentary succession in this region reflects a complex history of marine regression, fluvial deposition, and deltaic progradation during the Paleocene to Eocene.

Structurally, the study area is generally stable, with minimal tectonic deformation. However, minor fracturing and jointing occur locally within exposed sedimentary units, likely resulting from compactional stresses and regional basin subsidence. These structures occasionally enhance secondary porosity and influence groundwater flow patterns.

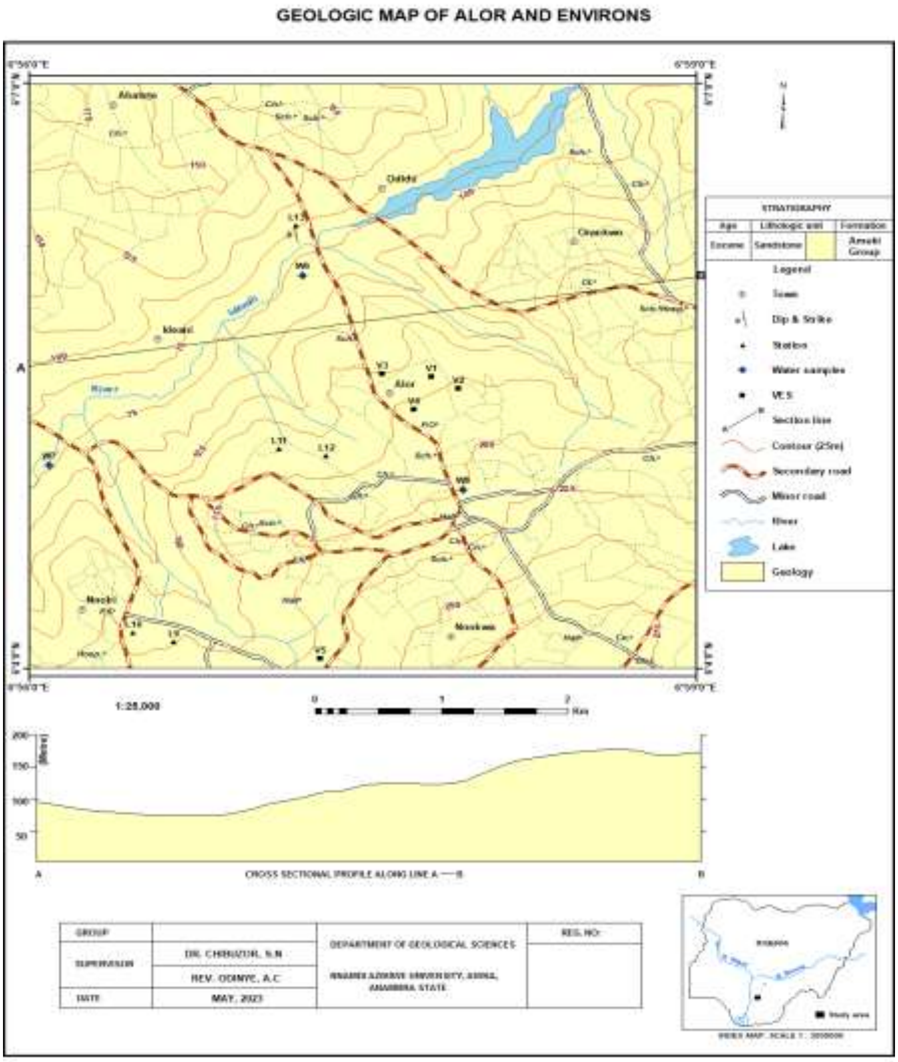

Fig. 2: Geologic map of the study area

METHODOLOGY

This study employed an integrated methodological approach combining geological field mapping, geophysical surveys, and hydrochemical analyses to evaluate groundwater potential in Alor and its environs within the Niger Delta Basin. The workflow was designed to characterize subsurface lithology, delineate aquifer systems, and assess groundwater quality for sustainable water resource development.

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Detailed geological mapping was conducted to identify surface lithologies, stratigraphic relationships, and structural features across the study area. Outcrops were systematically examined, and their geographic coordinates were recorded using a handheld Global Positioning System (GPS) device. These field observations facilitated the production of a geological map of the study area and aided in understanding the nature and extent of the Nanka Formation, the principal aquifer-bearing unit.

A total of five (5) Vertical Electrical Sounding (VES) stations were established across the study area using the Schlumberger electrode configuration. The method was chosen for its effectiveness in delineating subsurface layering, estimating aquifer depth, and characterizing resistivity variations within sedimentary terrains. The VES results enabled identification of geoelectric layers and provided insights into aquifer depth, and potential yield.

To evaluate water quality and suitability for domestic and agricultural use, three water samples were collected from key locations in the study area. Samples were collected in clean, sterilized containers following standard protocols. Physical, chemical, and bacteriological parameters were analysed in the laboratory. Laboratory analyses followed standard APHA (American Public Health Association) water quality procedures.

RESULTS AND DISCUSSION

Hydrochemical Results

Table 1: Summary of Hydrochemical Parameters in the Study Area

Parameter	Mmiri Ezigbo Odida (Surface Water)	Obiaja Stream (Surface Water)	St Mary's Borehole (Groundwater)	WHO/NSDWQ Standard Limit
Ph	6.90	6.48	7.30	6.5 – 8.5
Temperature (°c)	21.90	22.20	24.50	No health-based limit
Conductivity (µs/cm)	5.90	7.10	5.40	< 1000 µS/cm
Chloride (mg/l)	46	74	67	< 250 mg/L
Sulphate (mg/l)	125.096	122.627	92.176	< 250 mg/L
Bicarbonate (mg/l)	12	16	24	No direct limit
COD (mg/l)	216	144	125	< 10 mg/L (surface water guideline)
BOD (mg/l)	192	160	352	< 5 mg/L (unpolluted water)
DO (mg/l)	9.60	8.00	17.60	5–14 mg/L typical natural water
Hardness (mg/l)	90	128	160	< 150 mg/L (NSDWQ)
Lead (pb) (ppm)	0.189	0.053	0.037	< 0.01 ppm
Copper (cu) (ppm)	0.400	0.500	0.105	< 2.0 ppm
Iron (fe) (ppm)	0.000	0.000	0.026	< 0.3 ppm
Sodium (ppm)	1.469	1.484	1.141	< 200 ppm

Magnesium (ppm)	0.112	0.030	0.012	< 50 ppm
Potassium (ppm)	0.065	0.000	0.000	No health-based limit
Mercury (hg) (ppm)	0.730	0.046	0.025	< 0.006 ppm
Chromium (cr) (ppm)	1.158	1.483	2.973	< 0.05 ppm
Calcium (ppm)	0.344	0.569	0.488	No health-based limit
Arsenic (ppm)	0.034	0.110	0.016	< 0.01 ppm
Turbidity (ntu)	1.80	2.00	1.60	< 5.0 NTU
E. Coli	Present	Present	Present	

The hydrochemical analysis reveals significant differences between surface water and groundwater samples, although both exhibit parameters exceeding recommended WHO thresholds for potable water.

Physical Parameters

The surface water samples (pH 6.48-6.90) are slightly acidic, while groundwater (pH 7.30) is mildly alkaline and they all fall close to the acceptable 6.5-8.5 WHO/NSDWQ range (WHO, 2017). The slightly acidic surface waters likely reflect organic decay and runoff, whereas the alkaline groundwater indicates longer residence time and interaction with carbonate-rich aquifer materials. Similar slightly acidic to mildly alkaline conditions have been reported for groundwater in Nanka Sands and other parts of southeastern (Ezeh & Ugwu, 2010; Ocheri *et al.,* 2014).

All EC values are extremely low (5.40 - 7.10 µS/cm), far below the WHO/NSDWQ guideline of <1000 µS/cm**.** This indicates very low mineralization and suggests relatively “soft” water in terms of total dissolved ions. Similar low salinity waters have been documented in the Nanka Sands and other southeastern aquifers dominated by clean, permeable sands (Egboka & Nwankwor, 1983; Mgbenu & Egbueri, 2019). Turbidity values (1.6-2.0 NTU) are below the 5 NTU limit for drinking water, implying low visible suspended solids and reasonable clarity. However, “clear” water here is misleading because serious chemical and microbiological contamination is still present.

DO (8.0–17.6 mg/L) lies within or slightly above typical natural water ranges (5-14 mg/L). Elevated DO in the groundwater sample may reflect aeration during pumping or sampling, or mixing with shallow, oxygenated recharge. High DO despite high BOD/COD confirms that strong organic pollution is present but the system is still oxygenated, which can accelerate oxidation of metals. Total hardness increases from surface water (90-128 mg/L) to groundwater (160 mg/L). The NSDWQ threshold for hardness is 150 mg/L (desirable), so groundwater is slightly above the recommended level and can be classified as moderately hard. This is consistent with longer water-rock interaction in the deeper aquifer. Similar moderate hardness has been reported for Nanka Formation aquifers (Ehirim & Ebeniro, 2010).

Major anions and cations

The hydrochemical results indicate that the water in the study area is naturally fresh, weakly mineralized, and largely controlled by recent meteoric recharge, as shown by the very low concentrations of major cations such as sodium, potassium, calcium, and magnesium. These low values reflect minimal rock-water interaction and the highly permeable sandy aquifer system, which allows rapid infiltration with limited geochemical evolution. The major anions, chloride, sulphate, and bicarbonate, also occur at low to moderate levels within WHO and NSDWQ permissible limits. Bicarbonate concentrations suggest natural dissolution of CO_2 and minor

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue I January 2026

carbonate minerals, while the moderate chloride and sulphate levels indicate slight anthropogenic influence from domestic wastewater and surface runoff rather than significant industrial impact.

Heavy Metals

Despite the naturally good geochemical quality, the water is severely compromised by very high concentrations of heavy metals, particularly lead, mercury, chromium, and arsenic, all of which exceed WHO standards by wide margins. These elevated metal levels point to strong anthropogenic contamination from waste disposal, metal workshops, vehicle repair activities, and similar sources. Their presence in both surface and groundwater highlights the vulnerability of the sandy aquifer to pollutant infiltration.

Microbial Contamination

The detection of *E. coli* in all sampled water confirms widespread faecal contamination, likely resulting from poor sanitation, leaking septic systems, direct surface input, and inadequate borehole protection. This microbial contamination poses a significant health risk and further demonstrates that, although the aquifer's natural chemistry is favourable, the combined impact of heavy metals and faecal pollutants renders the water unsafe for drinking and domestic use without appropriate treatment and improved sanitary management.

Geophysical Analysis

The geophysical investigation across the study area, based on five Vertical Electrical Sounding (VES) stations, delineates a characteristic subsurface sequence composed of thin topsoil underlain by sand, clayey sand, dry sand, and a prominent water saturated sandstone aquifer. The topsoil shows resistivity values ranging from 55.42 to 711.82 Ω-m with corresponding thicknesses of 2.09 to 2.32 m, indicating a shallow, weakly consolidated surface layer. Beneath this unit, the key aquiferous horizon (the saturated sandstone) displays significantly higher resistivity values between 1213.30 and 5442.30 Ω-m and forms a continuous, permeable groundwater reservoir with an estimated thickness of 24.78 to 36.07 m across the area. Interpretation of the geo-electric sections and the resulting water table map reveals notable spatial variations in groundwater levels, shaped primarily by differences in topography and aquifer geometry. Specifically, VES 5 shows the shallowest depth to groundwater, suggesting a low-lying area with rapid recharge potential, while VES 4 records the deepest groundwater level, likely corresponding to elevated terrain where the water table lies further below the surface. Collectively, the VES results confirm the presence of a laterally extensive, high-yield sandstone aquifer typical of the Nanka Formation. However, the predominantly unconfined to semi-confined nature of this aquifer system also suggests a high susceptibility to contamination from surface sources, a condition further supported by the hydrochemical evidence.

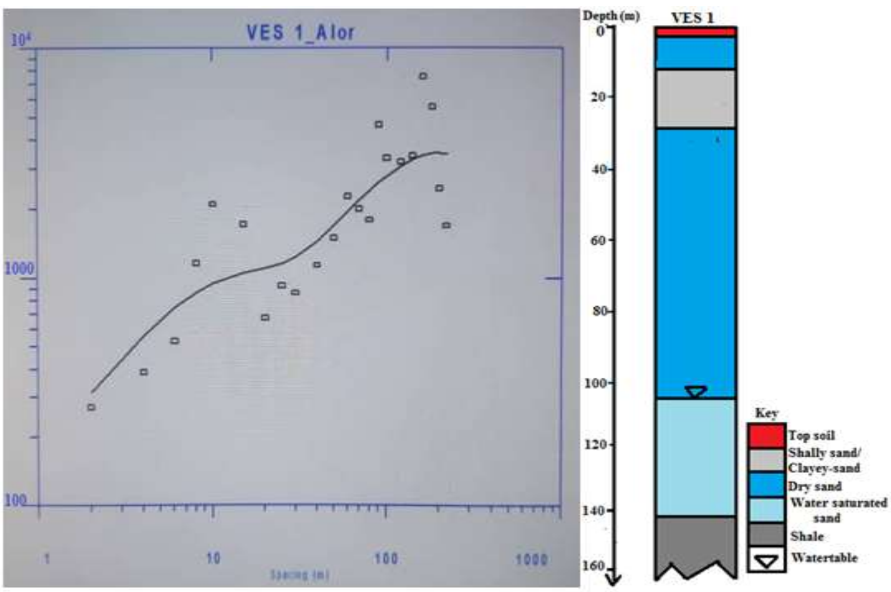

Fig. 3: Sounding curve for VES 1

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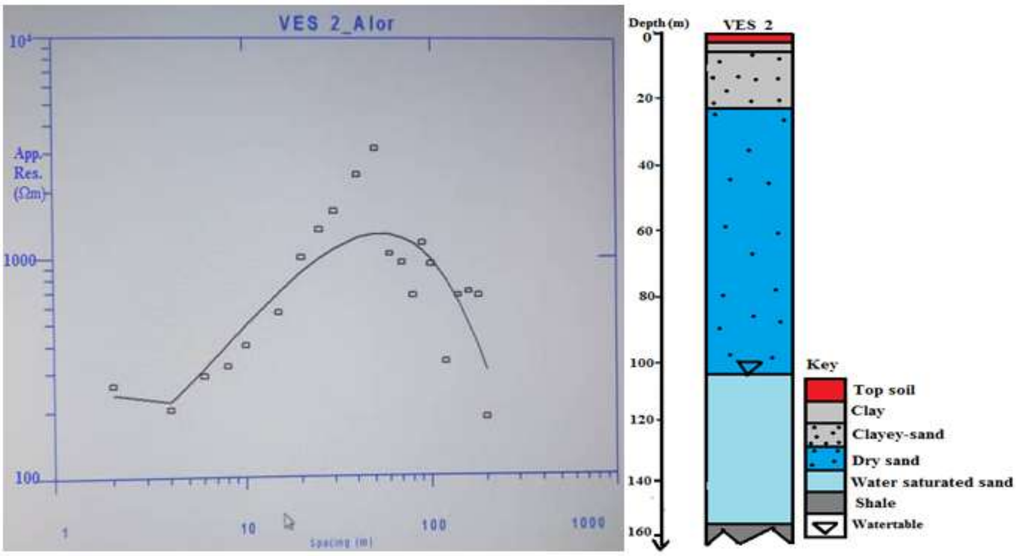

Fig. 4 : Sounding curve for VES 2

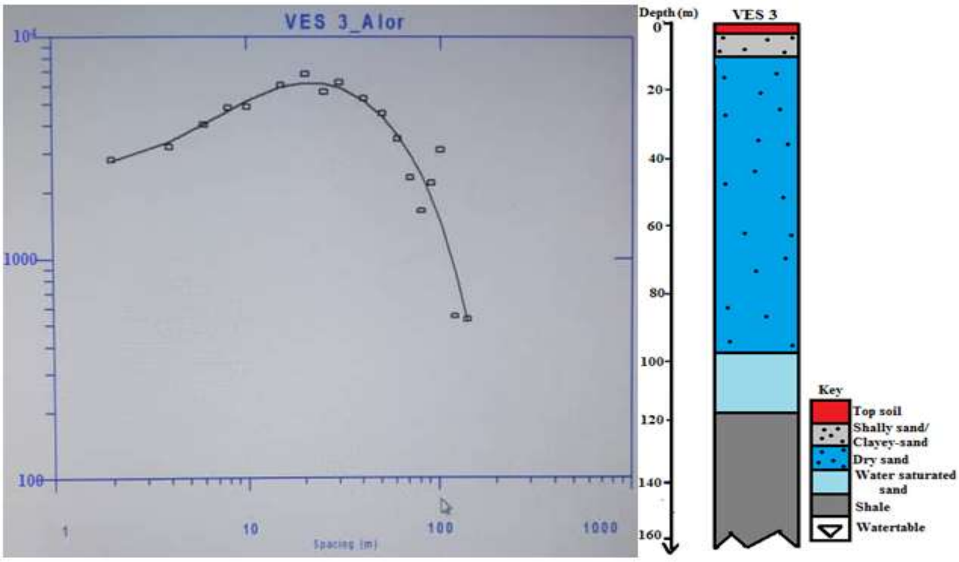

Fig. 5: Sounding curve for VES 3

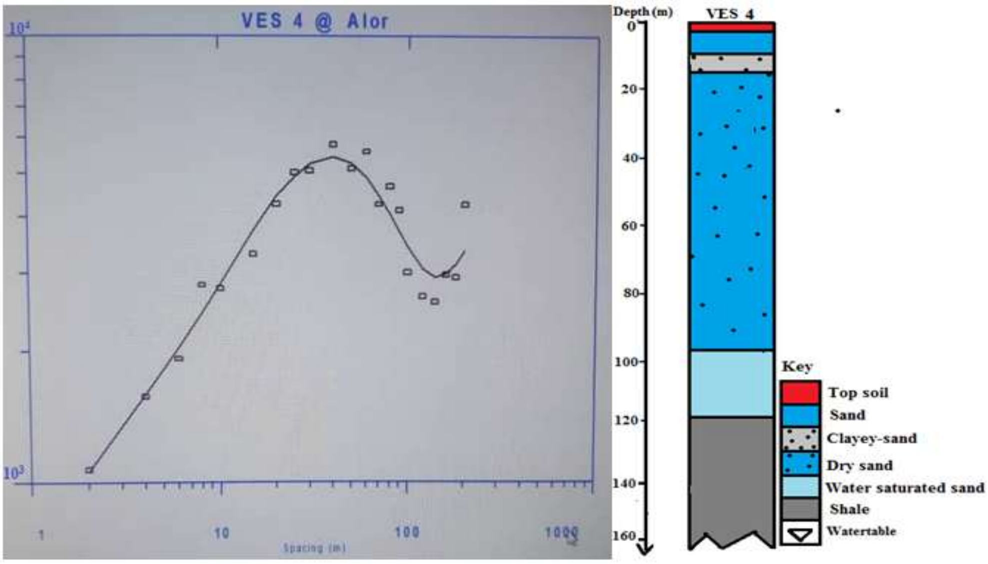

Fig. 6: Sounding curve for VES 4

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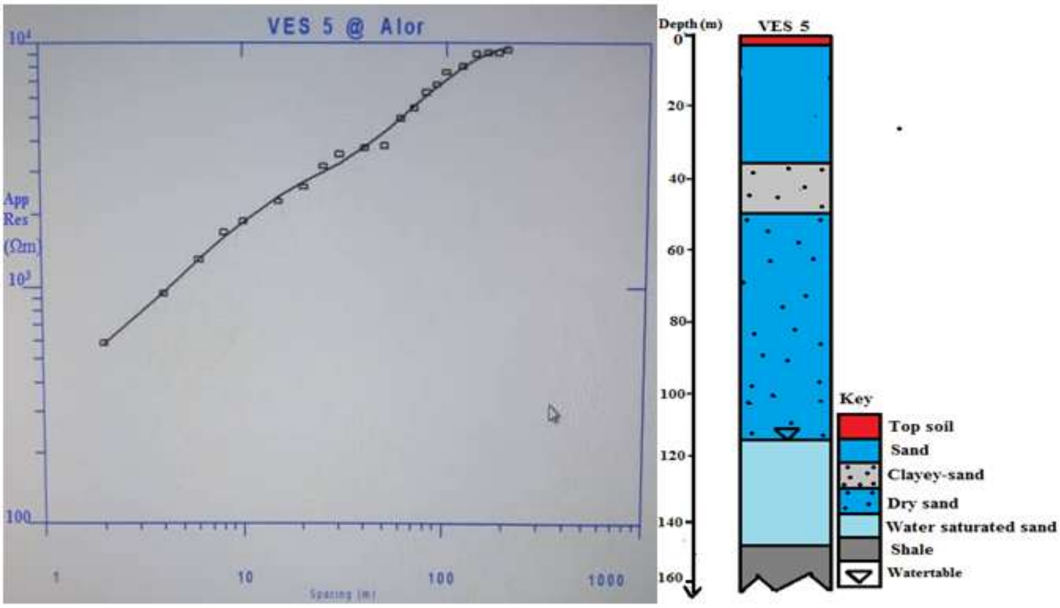

Fig. 7: Sounding curve for VES 5

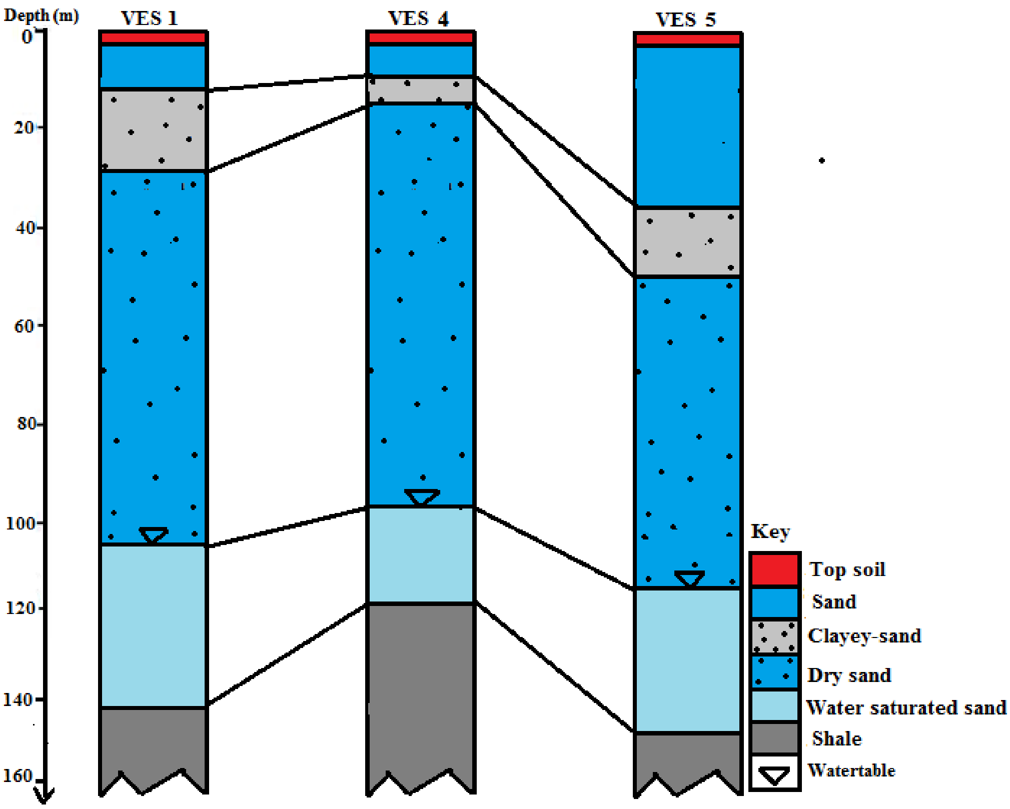

Fig. 8: A vertical geoelectric correlation through VES station 1, 4, and 5.

Water Table Map

The water table map of the study area was determined from the geolectric survey data, and the results were contoured to produce a detailed water table map, highlighting variations in groundwater levels across the area. It reveals distinct spatial variations in groundwater levels, as indicated by the contour values ranging from approximately 94 m to 117 m. The highest water table elevations occur in the northern part of the map, particularly around VES 1, VES 2, VES 3, and VES 4, where contour values range from 110-117 m. These elevated contours represent a groundwater recharge zone, likely associated with higher topographic elevation and increased infiltration. The close spacing of contour lines in this northern zone indicates a steep hydraulic gradient, suggesting that groundwater flows rapidly away from this high point.

In contrast, the lowest water table elevations occur toward the southern portion of the map, around VES 5, where values drop to approximately 94-99 m. This area represents a groundwater discharge or accumulation zone, where subsurface flow converges or where groundwater appears closer to the surface. The broader spacing of contour lines here reflects a gentler hydraulic gradient and slower groundwater movement relative to the north.

Based on the overall pattern of decreasing contour values from north to south, the dominant groundwater flow direction is from the northern sector (VES 1-4) toward the southern sector (VES 5). This flow pattern is consistent with natural hydraulic principles, where groundwater moves from regions of higher hydraulic head to lower hydraulic head.

Hydrologically, this configuration implies that areas around VES 1-4 serve as major recharge zones and are therefore more sensitive to contamination from surface activities. Pollutants introduced in this upper zone are likely to migrate downgradient toward VES 5, where they may accumulate due to the relatively lower gradients. The southern zone (VES 5) is thus more vulnerable to receiving contaminants transported through the aquifer system.

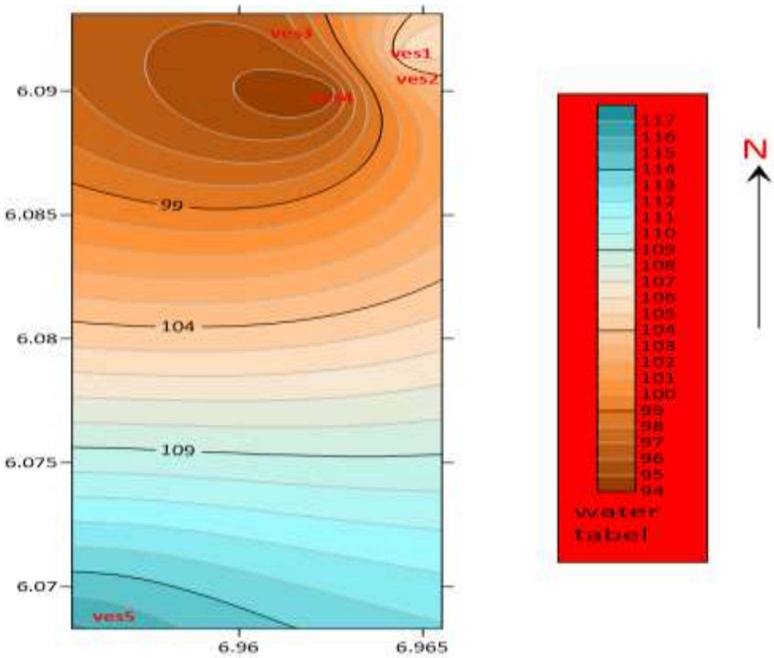

Fig. 9: Water table map of the study area.

CONCLUSION

This study demonstrates that groundwater within the study area, though naturally fresh and weakly mineralized, is significantly impacted by anthropogenic contamination. Hydrochemical results reveal elevated concentrations of heavy metals, including lead, mercury, chromium, and arsenic, far exceeding WHO and NSDWQ standards, along with widespread *E. coli* contamination, making the water unsafe for direct consumption. Geophysical results confirm the presence of a thick, permeable sandstone aquifer, but its predominantly unconfined nature increases vulnerability to surface pollutants. The water table configuration further indicates a north-south flow pattern that enhances contaminant migration. Thus, the groundwater system possesses good storage potential but lacks natural protective capacity, resulting in compromised water quality.

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